Dialogues in Health 1 (2022) 100006

Contents lists available at ScienceDirect

Dialogues in Health

journal homepage: www.elsevier.com/locate/dialog

Anthropometric indices, but not birth weight, are associated with high blood pressure risk among Malay adolescents in Kuala Lumpur

Bee Koon Poh [a,*], Yeow Nyin Ang [a], Giin Shang Yeo [a], Yong Zhuan Lee [a], Shoo Thien Lee [a], Jasmine Siew Min Chia [b], Bee Suan Wee [c]

[a] Nutritional Sciences Programme & Centre for Community Health Studies (ReaCH), Faculty of Health Sciences, Universiti Kebangsaan Malaysia, 50300 Kuala Lumpur, Malaysia
[b] Faculty of Dentistry, Universiti Kebangsaan Malaysia, 50300 Kuala Lumpur, Malaysia
[c] School of Nutrition and Dietetics, Faculty of Health Sciences, Universiti Sultan Zainal Abidin, 21300 Kuala Nerus, Terengganu, Malaysia

ARTICLE INFO

Article history:
Received 23 October 2021
Received in revised form 23 February 2022
Accepted 28 February 2022
Available online 4 March 2022

Keywords:
Adolescent
Anthropometry
Birth weight
Blood pressure
Malaysia

ABSTRACT

Background: With the high prevalence of hypertension, it is important to determine its predictors early. The aim of this study was to determine the association between blood pressure with anthropometric indices and birth weight among a population of Malay adolescents in Kuala Lumpur.
Design and methods: This cross-sectional study was carried out among 254 primary and secondary school adolescents aged 10 to 16 years. Anthropometric measurements and blood pressure were determined through standardized protocols, while participants' birth weight was obtained from birth certificate. Body mass index (BMI), waist-to-hip ratio (WHR), waist-to-height ratio (WHtR) and a body shape index (ABSI) were calculated.
Results: Boys had significantly higher weight, height, WC, WHtR and systolic blood pressure (SBP) than girls ($p < 0.05$). SBP was moderately correlated with body weight ($r = 0.60$), WC ($r = 0.55$), BMI ($r = 0.54$), height ($r = 0.47$), WHtR ($r_s = 0.36$) and WHR ($r = 0.30$). Moderate correlations were found between diastolic blood pressure (DBP) with BMI ($r = 0.26$), WC ($r = 0.23$) and body weight ($r = 0.20$). Participants with BMI > +1SD had higher odds of being prehypertensive or hypertensive (aOR 8.97; 95% CI 3.16, 25.48), followed by participants with WC ≥ 90th percentile (aOR 6.31; 95% CI 2.48, 16.01) and participants with WHtR > 0.5 (aOR 5.10; 95% CI 2.05, 12.69). Multiple linear regression showed BMI was positively associated with both SBP and DBP. No significant association was found between birth weight and BP.
Conclusion: BMI had the best predictive ability for SBP and DBP. These findings strongly emphasize the importance of primary prevention of hypertension in adolescents, especially among those with high BMI.

1. Introduction

Obesity in adolescence is a growing health issue that has become a global focus of attention. Among Malaysian children aged 5 to 17 years, the latest National Health and Morbidity Survey (NMHS) reported prevalence of overweight at 15% and obesity at 14.8% in 2019 [1]. The high prevalence of overweight and obesity among this age group is worrying because of the accompanying metabolic syndrome that usually follow in the later stages of life. Previous studies have reported that children with overweight and obesity are more likely to develop such syndromes as diabetes and hypertension [2,3]. Adolescence is also the period during which dietary and lifestyle practices are developed that often persist into adulthood. With the nutrition transition, greater availability of sweetened beverages and fast foods, and increasingly sedentary lifestyles, many adolescents are reportedly overeating and becoming physically inactive, leading to increase in adiposity [4].

Obesity has been reported to be one of the factors that contribute to the increment in blood pressure (BP) [5]. Raised BP is a complex disorder resulting from genetic, environmental, vascular, demographic and neuroendocrine factors [6]. Growing evidence indicates that abnormal BP (BP ≥ 95th percentile) during adolescence increases the risk of hypertension, coronary artery calcifications and cardiovascular complications during adulthood [7]. The NHMS 2019 reported that the prevalence of hypertension among Malaysian adults 18 years and older was 30.0% [1]. The

Abbreviations: ABSI, A Body Shape Index; aOR, Adjusted Odds Ratio; BMI, Body Mass Index; BP, Blood Pressure; CI, Confidence Interval; DBP, Diastolic Blood Pressure; LBW, Low Birth Weight; MOE, The Ministry of Education; NHBPEP, National High Blood Pressure Education Program; NHMS, National Health and Morbidity Survey; OR, Odds Ratio; SBP, Systolic Blood Pressure; SD, Standard Deviation; SE, Standard Error; SEANUTS, South East Asian Nutrition Surveys; TEM, Technical Error of Measurement; WC, Waist Circumference; WHO, World Health Organization; WHR, Waist-to-hip Ratio; WHtR, Waist-to-height Ratio.

* Corresponding author.
E-mail address: pbkoon@ukm.edu.my (B.K. Poh).

http://dx.doi.org/10.1016/j.dialog.2022.100006

prevalence increases with each increasing age group, from 5.7% in the 20–24-year-olds to 81.7% among those 75 years and older. This could contribute to increased risks of hospitalization, which will undoubtedly heighten the burden on the country's healthcare system. Hence, provision of health education and healthcare to adolescents need to emphasize on preventing and controlling hypertension from a young age.

Studies have found association between anthropometric indices of adiposity and high BP in adolescents [8], including in Malaysia [9]. As anthropometric indices are simple and cost-effective to use when assessing obesity and body adiposity, researchers frequently correlate anthropometric indices with hypertension risks. Many earlier epidemiological studies have consistently revealed the link between hypertension and various adiposity indices, including body mass index (BMI), waist circumference (WC), waist-to-hip ratio (WHR) and waist-to-height ratio (WHtR) [5,10]. BMI is perhaps the most widely established indicator used in evaluating obesity, while other anthropometric indices, such as WC, WHR and WHtR, have also been used to evaluate the accumulation of central adiposity [5]. A Body Shape Index (ABSI) was proposed as an alternative anthropometric index to determine the relative contribution of WC to central obesity, which is independent of BMI, body weight and height [11].

Individuals born with low birth weight (LBW) are reported to be susceptible to hypertension, cardiovascular disease and other chronic diseases in later life [12]. Uterine life is a vital period for the rapid growth, cellular differentiation and functional maturation of the fetal organs [12]. Therefore, preterm birth (gestation period less than 37 weeks) or intrauterine growth restriction can contribute to growth impairment, which eventually leads to LBW in newborns. A recent retrospective cohort study in Sri Lanka revealed LBW to be significantly associated with hypertension, specifically systolic blood pressure (SBP), among adults [13]. The inverse association between LBW and hypertension has been highlighted in the past decade [14,15], therefore further research is needed to consider LBW as a confounding factor towards increased risk of hypertension in adolescence and adulthood.

Currently, there is limited research on the correlation of anthropometric indices and birth weight with hypertension in Malaysian adolescents. This present study, therefore, aims to investigate the relationship between anthropometric indices and birth weight with BP in Malay adolescents and to determine the best anthropometric index to predict high BP in this population.

2. Design and methods

2.1. Study design

This cross-sectional study was conducted using single stage cluster sampling, in six primary and ten secondary schools located in three zones of Kuala Lumpur, namely Bangsar/Pudu, Sentul and Keramat. The inclusion criteria for participants were Malay adolescents aged 10 to 16 years. Exclusion criteria were adolescents with mental or physical disabilities, and those on medication or treatment that would affect their BP.

The sample size was calculated using the Cole (1997) formula [16] to investigate the correlation between anthropometric indices and birth weight with BP:

$$n = \frac{\left(Z_{1\text{-}\alpha/2} + Z_{1\text{-}\beta}\right)^2}{d^2/\left(1\text{-}d^2\right)} + 5$$

where n is the required sample size, $Z_{1\text{-}\alpha/2}$ (1.96) and $Z_{1\text{-}\beta}$ (0.84) are the values of the standard normal distribution at the 95% CI, and d is the estimated correlation between two variables. The correlation of 0.19 between WHR and DBP from Moser and colleagues' study [17] was chosen as the estimated correlation (d). Based on the stated formula, the required sample size for this study was 214. With the additional adjustment of 20% dropout rate, the recruited sample size were 268 participants. After the data cleaning process, a total of 14 participants with incomplete data (birth weight, anthropometry, socio-demographic information) were excluded. Thus, the final sample comprised 254 Malay adolescents, with equal number of boys and girls.

Study procedures were approved by the Research Ethics Committee of Universiti Kebangsaan Malaysia (Ref. No. UKM 1.5.3.5/222/NN-084-2011). Permission to carry out data collection was obtained from the Ministry of Education, Department of Education in Kuala Lumpur Federal Territory, and from the principals of the schools involved. Written informed consent from the parents or guardians and verbal assent from participants were also obtained prior to data collection.

2.2. Socio-demographic and birth weight information

Parents were required to provide such details as name, age, sex and ethnicity. Birth weight was obtained from the participants' birth certificates. Birth weight was grouped into three categories, following World Health Organization (WHO) 2010 guidelines [18], namely, low birth weight (<2.5 kg), normal birth weight (2.5–4.0 kg) and high birth weight (>4.0 kg).

2.3. Pubertal assessment

Participants' pubertal development on the Tanner Rating Scale [19,20] were self-reported by both male and female participants. The physical development of female breast, male genitalia and pubic hair growth based on the Tanner Rating Scale was explained in detail to respective participants prior to their self-assessment. The Tanner Rating Scale is divided into five stages: pre-puberty (Stage 1), puberty (Stages 2–4) and post-puberty (Stage 5).

3. Anthropometric status

Anthropometric measurements were taken by a primary trained observer with the assistance of two other trained observers using standardized protocol. Body weight was measured using SECA digital weighing scale (Model 880; SECA, Germany) to the nearest 0.1 kg, with participants dressed in light clothing and barefooted. Height was measured using SECA stadiometer (Model 214; SECA, Germany) to the nearest 0.1 cm. Waist circumference (WC) was measured using Lufkin tape (Model W606PM; Apex Tool Group, United States) to the nearest 0.1 cm. The midpoint waist circumference between the 10th rib and iliac crest was measured, at the end of a normal expiration, without compressing the skin [21]. Hip circumference was measured at the maximum posterior protuberance of the buttocks [22]. The technical error of measurement (TEM) for anthropometric measurements in this study ranged from 3% to 4%, which is well within the target intra-observer TEM values (below 7.5%) [23].

Body mass index (BMI) is expressed as body weight in kilograms (kg) divided by height in meters squared (m^2). The results were then divided into four groups, which were: thinness (< -2 SD), normal (-2 SD to $+1$ SD), overweight ($> +1$ SD to $\leq +2$ SD) and obese ($> +2$ SD), based on WHO 2007 growth reference for 5–19 years. [24] WC was grouped into abdominal obesity ($\geq$90th percentile) and abdominal non-obese (<90th percentile), according to Poh et al. [25] WHR is calculated as the ratio of WC (cm) to hip circumference (cm), whereas WHtR is calculated as the ratio of WC (cm) to height (cm). WHtR was categorised into abdominal obesity (>0.5) and abdominal non-obese ($\leq$0.5), according to Ashwell and Hsieh [26].

ABSI was calculated based on WC that is independent of height and body mass [11]. The formula used to calculate ABSI is as follows:

$$ABSI = WC/\left(BMI^{\frac{2}{3}} \times height^{\frac{1}{2}}\right)$$

3.1. Blood pressure

Blood pressure was measured in mmHg using an Omron digital automated BP monitor model HEM 907 (Omron, Japan) by three trained observers. BP is measured when participants have rested and sat quietly for five minutes, with their back and left arm supported, feet relaxed and flat on the floor and the cubital fossa (elbow pit) situated at the heart level [27]. Participants were requested to place the left arm with the palm of hand facing upwards. A cuff size suitable for the participant's arm was placed with the artery position mark on the cuff aligned with the brachial artery. Placement of the lower cuff edge is measured to be 1.2 to 2.5 cm above the interior elbow joint. BP was then measured on the left arm; readings were taken twice with a 1-min interval in between. The average of the two values for each measurement was then used in the data analysis. According to NHBPEP for preadolescents aged 10–12 years [27] and Flynn et al. [28] for adolescents aged 13 years and above, hypertension is defined as average SBP and/or DBP, which are ≥95th percentile, or ≥130/80 mmHg, respectively. Prehypertension (or elevated BP) is defined as average SBP or DBP that are ≥90th percentile but <95th percentile for preadolescents, and SBP of 120–129 mmHg and DBP lower than 80 mmHg for adolescents. Participants that have SBP and DBP that are <90th percentile, or <120/80 mmHg, are considered to have normal BP.

3.2. Statistical analysis

Data were analyzed using IBM Statistical Product and Service Solutions Statistics version 22.0 (IBM, Chicago, United States). Descriptive statistics, including mean and percentage were used to describe the socio-demographic characteristics, birth weight, anthropometric and BP measurements. Independent *t*-tests were performed to determine the differences in physical characteristics, anthropometric indices, birth weight and BP between the sexes. The correlation between physical characteristics, anthropometric indices and birth weight with BP were then determined by Pearson and Spearman correlation tests. Chi-squared test was performed to evaluate the association between categorical variables. Logistic regression was done to assess the association between anthropometric indices (BMI, WC, WHtR), birth weight and prehypertension/hypertension. Crude and adjusted odds ratio (for age and sex) with 95% confidence intervals were estimated for the entire dataset. Multiple linear regressions were conducted to identify the influence of significant anthropometric indices on blood pressure. All independent variables, such as weight, height, BMI, WC, WHR, WHtR, age and sex, were included in the multiple linear regression analysis with backward elimination method. All statistical tests were 2-sided, and significance level was set at $p < 0.05$.

4. Results

Table 1 shows the physical characteristics, anthropometric measurements and blood pressure of the subjects. The mean age of boys and girls were 13.1 ± 1.8 and 13.2 ± 1.8 years, respectively. Boys were heavier ($p < 0.05$), taller ($p < 0.05$), had larger WC ($p < 0.05$) and higher WHR ($p < 0.001$) than girls. Significantly higher SBP was found amongst boys than girls (105.2 ± 12.1 mmHg vs. 100.5 ± 10.2 mmHg, $p < 0.01$), while no statistical difference was demonstrated in DBP between the two sexes (boys 57.6 ± 7.7 mmHg; girls 58.4 ± 8.4 mmHg). Moreover, the blood pressure measurements of both sexes were found to be in the range of normal blood pressure. With regard to birth weight, no significant difference was found; boys were 3.1 ± 0.5 kg, while girls were 3.0 ± 0.5 kg. Similarly, the ABSI of both sexes demonstrated similar results (0.07 ± 0.01) with no significant difference.

Results on puberty, anthropometric indices, birth weight and BP (expressed in percentages) for boys and girls are provided in Table 2. The majority of the participants were going through puberty (93.3%), with only small proportions in pre-pubertal (5.5%) and post-pubertal (1.2%) stages. A third of the participants (31.5%) were classified as overweight or obese; the proportion of boys with overweight or obesity (37.0%) was higher than that of girls (26.0%). Approximately a fifth of the participants were categorized as abdominally obese, based on WC (16.5%) and WHtR (21.7%). Abdominal obesity was more prevalent in boys than in girls according to both WC (boys 20.5%; girls 12.6%) and WHtR (boys 26.8%; girls 16.5%). Most of the participants were classified as normal birth weight (boys 83.5%; girls 85.0%), whilst LBW was noted only in 12.6% of the participants. Some 8.6% of the participants had either prehypertension or hypertension, with a slightly higher proportion among boys (10.2%) than girls (7.1%).

Table 3 depicts the correlation of BP with physical characteristics, anthropometric indices and birth weight. Moderate correlations were found between SBP and body weight ($r = 0.60$, $p < 0.001$), WC ($r = 0.55$, $p < 0.001$) and BMI ($r = 0.54$, $p < 0.001$), height ($r = 0.47$, $p < 0.001$), WHtR ($r_s = 0.36$, $p < 0.001$) and WHR ($r = 0.30$, $p < 0.001$). Moderate correlations were also observed between DBP with anthropometric indices in BMI ($r = 0.26$, $p < 0.001$), followed by WC ($r = 0.23$, $p < 0.001$) and body weight ($r = 0.20$, $p < 0.01$). On the contrary, no significant correlation was observed between ABSI and birth weight with either SBP or DBP.

Table 4 illustrates the odds ratios and confidence intervals for the presence of prehypertension or hypertension in relation to anthropometric indices above the proposed cut-off values and birth weight below the cut-off values. Adolescents with BMI > +1 SD were 8.97 times more likely (aOR 8.97; 95% CI 3.16, 25.48) to become prehypertensive or hypertensive than their thin or normal weight counterparts. Meanwhile, adolescents with WC ≥ 90th percentile and WHtR > 0.5 were found to have higher odds of being prehypertensive (aOR 6.31; 95% CI 2.48, 16.01) or

Table 1
Physical Characteristics, Anthropometric Variables, Birth Weight and Blood Pressure (mean ± SD).

Characteristics	Girls ($n = 127$)	Boys ($n = 127$)
Age (years)	13.2 ± 1.8	13.1 ± 1.8
Weight (kg)	45.9 ± 13.7	50.5 ± 18.2*
Height (cm)	150.1 ± 8.4	153.1 ± 12.3*
Birth Weight (kg)	3.0 ± 0.5	3.1 ± 0.5
Waist Circumference (WC) (cm)	65.7 ± 11.4	69.2 ± 14.3*
Hip Circumference (cm)	84.5 ± 10.9	83.4 ± 13.0
Body Mass Index (BMI) (kg/m^2)	20.1 ± 4.9	21.1 ± 5.7
Waist-to-Hip Ratio (WHR)	0.77 ± 0.06	0.83 ± 0.07***
Waist-to-Height Ratio (WHtR)	0.44 ± 0.07	0.45 ± 0.08
A Body Shape Index (ABSI)	0.07 ± 0.01	0.07 ± 0.01
Systolic Blood Pressure (SBP)	100.5 ± 10.2	105.2 ± 12.1**
Diastolic Blood Pressure (DBP)	58.4 ± 8.4	57.6 ± 7.7

Significant differences when compared to girls at $*p < 0.05$, $**p < 0.01$ and $***p < 0.001$ using independent *t*-test.

Table 2
Proportion of Adolescents by Pubertal Stages, Anthropometric Indices, Birth Weight and Blood Pressure Categories.

Category	Girls ($n = 127$) n (%)	Boys ($n = 127$) n (%)	Total ($n = 254$) n (%)
Pubertal Stage			
Pre-puberty	4 (3.1)	10 (7.9)	14 (5.5)
Puberty	123 (96.9)	114 (89.8)	237 (93.3)
Post-puberty	0 (0)	3 (2.3)	3 (1.2)
BMI*			
Thinness	3 (2.4)	5 (3.9)	8 (3.1)
Normal	91 (71.6)	75 (59.1)	166 (65.4)
Overweight	18 (14.2)	14 (11.0)	32 (12.6)
Obese	15 (11.8)	33 (26.0)	48 (18.9)
WC*			
<90th percentile	111 (87.4)	101 (79.5)	212 (83.5)
≥90th percentile	16 (12.6)	26 (20.5)	42 (16.5)
WHtR*			
≤0.5	106 (83.5)	93 (73.2)	199 (78.3)
>0.5	21 (16.5)	34 (26.8)	55 (21.7)
Birth Weight			
Low (<2.5 kg)	16 (12.6)	16 (12.6)	32 (12.6)
Normal (2.5–4.0 kg)	108 (85.0)	106 (83.5)	214 (84.3)
High (>4.0 kg)	3 (2.4)	5 (3.9)	8 (3.1)
BP			
Normal	118 (92.9)	114 (89.8)	232 (91.4)
Prehypertension	6 (4.7)	4 (3.1)	10 (3.9)
Hypertension	3 (2.4)	9 (7.1)	12 (4.7)

Significant differences in proportion distribution of anthropometric indices between the sexes at $*p < 0.05$ using chi-squared test.

Table 3
Correlation of Blood Pressure with Physical Characteristics, Anthropometric Indices and Birth Weight.

Variables	SBP			DBP		
	Girls	Boys	Overall	Girls	Boys	Overall
Age (years)	0.11	0.25**	0.18**	−0.09	−0.16	−0.12
Weight (kg)	0.47***	0.67***	0.60***	0.16	0.26**	0.20**
Height (cm)	0.34***	0.52***	0.47***	−0.03	0.06	0.02
Birth Weight (kg)	0.18*	−0.01	0.10	0.13	−0.04	0.04
BMI (kg/m^2)	0.44***	0.61***	0.54***	0.20*	0.32***	0.26***
WC (cm)	0.42***	0.62***	0.55***	0.16	0.31***	0.23***
WHR	0.15	0.32***	0.30***	0.08	0.26**	0.14*
WHtR	0.26††	0.44†††	0.36†††	0.09	0.24††	0.17††
ABSI	−0.11	−0.05	−0.06	−0.05	0.06	−0.01

Pearson correlation, r: Significant at *$p < 0.05$, **$p < 0.01$ and ***$p < 0.001$.
Spearman correlation, r_s: Significant at ††$p < 0.01$ and †††$p < 0.001$.

hypertensive (aOR 5.10; 95% CI 2.05, 12.69), as compared to their abdominally non-obese counterparts. However, birth weight was not significantly associated with prehypertension or hypertension among adolescents.

Table 5 shows the multiple linear regression models for predicting SBP and DBP. The equation of SBP model was SBP = 36.925 + 0.915(BMI) + 0.450(Height) − 1.334(Age) + 2.396(Sex) [Male = 1, Female = 0] and explained about 40.2% of variance in the SBP. The other equation, DBP = 60.289 + 0.472(BMI) − 0.911(Age), explained only 9.7% of variance in DBP. BMI was the main predictor for both SBP and DBP. BMI was positively associated with BP, while age was negatively associated with BP.

5. Discussion

The study demonstrates a strong association between obesity and increased odds of elevated BP and hypertension. BMI was found to be the best predictor among the anthropometric indices evaluated in this study, as an early indicator of hypertension among Malay adolescents. Conversely, no associations were found between birth weight and elevated BP and hypertension.

Overall, a third of the adolescents were observed to have problems with overweight and obesity. This is in agreement with other studies conducted among Malaysian adolescents [29,30]. Boys were more likely to be classified as overweight or obese, or have higher WC with a tendency towards abdominal obesity [31–33]. Additionally, deposition of fat in the central region increases with puberty and maturation events in males, which results in a more android body shape [34]. This is in accordance with the findings of our study whereby more boys were found to have abdominal obesity than girls. Girls are usually more conscious of their body shape, frequently resulting in daily food intake restrictions [29].

Table 5
Multiple Linear Regression with Stepwise Backward Elimination Method to Predict Anthropometric Indices Influencing SBP and DBP.

	B	SE	95% CI	Beta	t-test	*p-value*
Predictor variables for SBP						
BMI	0.915	0.113	0.691, 1.138	0.427	8.060	<0.001
Height	0.450	0.073	0.306, 0.594	0.419	6.161	<0.001
Age	−1.334	0.407	−2.135, −0.533	−0.212	−3.279	0.001
Sex	2.396	1.133	0.165, 4.627	0.105	2.115	0.035
Predictor variables for DBP						
BMI	0.472	0.094	0.286, 0.657	0.311	5.011	<0.001
Age	−0.911	0.278	−1.455, −0.366	−0.205	−3.294	0.001

B: parameter estimates, SE: standard error, 95% CI: 95% confidence intervals of parameter estimates, Beta: standardised estimates.

SEANUTS, a nationally-representative study among children aged 6 months to 12 years old, also reported that Malaysian boys consume higher amounts of energy and macronutrients daily compared with girls [35].

Studies have also demonstrated that BP increases more rapidly during the pubertal growth spurt than before or after [36,37]. This occurs in both sexes, with boys having significantly higher increase in BP than girls. SBP was found to increase significantly more in boys than in girls while DBP increased more in girls than in boys [36,37]. Similar pattern was found in the present study, where boys had significantly higher SBP than girls. However, boys tend to have lower DBP than girls although it was not statistically significant.

In our study conducted in Kuala Lumpur, the capital city of Malaysia, we found a lower prevalence of hypertension and prehypertension (8.6%) as compared to previous local studies. The prevalence of hypertension among adolescents in two nearby locations, Putrajaya and Selangor, were reportedly 22.7% and 25.6%, respectively [38,39]. This disparity of results could be due to the different types of instruments used in measuring BP (present study: digital automated BP monitor; Rampal et al. [38] and Sreeramareddy et al. [39]: manual auscultatory mercury sphygmomanometer). A cross-sectional study conducted with patients in Iranian hospitals supported the view that using manual BP measurement method could lead to BP readings that were higher by 15 mmHg than readings taken by automated measurement method [40]. Additionally, there may be differences in BP readings from the right and left arms; a previous study has suggested a bias towards higher readings from the right arm [41]. However, standardized protocol for BP measurement was performed in this study to improve the accuracy of BP assessments. The prevalence of hypertension

Table 4
Association of Prehypertension/Hypertension and Normal Blood Pressure Groups According to Anthropometric and Birth Weight Categories.

Parameter	Normal blood pressure (N = 232) n (%)	Prehypertension/ Hypertension (N = 22) n (%)	OR (95% CI)	aOR (95% CI)
BMI > +1 SD#				
Yes	63 (78.8)	17 (21.2)	9.12 (3.23, 25.76)*	8.97 (3.16, 25.48)*
No	169 (97.1)	5 (2.9)	1.00	1.00
WC ≥ 90th percentile#				
Yes	31 (73.8)	11 (26.2)	6.48 (2.59, 16.23)*	6.31 (2.48, 16.01)*
No	201 (94.8)	11 (5.2)	1.00	1.00
WHtR > 0.5#				
Yes	43 (78.2)	12 (21.8)	5.27 (2.14, 13.00)*	5.10 (2.05, 12.69)*
No	189 (95.0)	10 (5.0)	1.00	1.00
Birth weight < 2.5 kg				
Yes	28 (87.5)	4 (12.5)	1.62 (0.51, 5.13)	1.60 (0.50, 5.10)
No	204 (91.9)	18 (8.1)	1.00	1.00

OR; crude odds ratio analysed by univariate logistic regression; aOR; adjusted odds ratio with age and sex, and analysed by univariate logistic regression.
Significant association of anthropometric indices with blood pressure at $p < 0.001$ by Chi- square test.
* Significant odds ratio at $p < 0.001$.

in our study was similar to the global prevalence reported in the meta-analysis by Song and colleagues, at 4.7 and 4.0, respectively. However, the prevalence of prehypertension (9.7%) in the global data of children and adolescents (≤19 years of age) was more than twice the prevalence found in our study (3.9%) [42].

Consistent with prior studies, individuals with overweight or obesity were found to have higher odds of hypertension [10,39]. Being overweight or obese intensifies the adverse effect of triglycerides, one of the most common body fats. Triglycerides initiate and enhance the endothelial cells' inflammatory responses to cytokines, promoting production of free radicals and endothelin-1 [43]. This leads to endothelial dysfunction and loss of endothelial vasomotor activity, consequently affecting the BP system [44]. Therefore, it is urgent that the relationship between anthropometric indices and BP is explored, as individuals with persistently raised BP may have increased risk of non-communicable diseases and cardiovascular complications [7].

The results of the present study conform to previous studies conducted among adolescents, which indicate the relationship between anthropometric indices and elevated BP [39,45]. In agreement with another previous study [10], our study also found higher prevalence of prehypertension or hypertension in boys (10.2%) than girls (7.1%). Higher correlations between BMI, WC, WHR and WHtR with BP in boys compared to girls were found in our study. In a study conducted in Sarawak, Malaysia, it was reported that female and male adolescents had different predictors of hypertension. For boys, WC was the best predictor of hypertension, whereas, for girls, BMI was the best predictor [9]. Another study conducted among adolescents aged 12–16 years in Selangor, Malaysia showed that WHtR was the best indicator to predict the presence of elevated BP in both sexes [45]. Although our study showed a relationship between anthropometric indices and hypertension, the strength of the correlations still varied, according to different factors. The reasons could include the environmental and genetic factors that affect hypertension. Besides that, the geographical origin of the participants may also have an influence on the strength of correlation [17]. Thus, future studies should consider how divergent geographical and environmental backgrounds affect the ability of anthropometric indices to predict hypertension.

The prevalence of overweight and obesity has been increasing over the years, as observed in NHMS reports. We found that adolescents with higher BMI poses the highest odds (aOR 8.97) of being prehypertensive or hypertensive, followed by higher WC (aOR 6.31) and higher WHtR (aOR 5.10), compared to their counterparts. This finding supports evidence from previous studies that BMI was significantly related to the odds of developing hypertension [8,9]. A recent study found that OR in the highest quartiles of BMI, WC and WHtR were significantly associated with prehypertension or hypertension, which were 6.85 [4.62], 5.65 [3.17], and 2.37 [2.31], in boys and [girls], respectively [8].

According to multiple linear regressions, BMI was the main predictor of hypertension in adolescents aged 10 to 16 years. Similar findings were reported in a local study involving adolescents aged 12 to 17 years, which also found BMI to be a good predictor of hypertension [9]. Furthermore, BMI was found to be positively associated with both SBP and DBP; this is supported by a local study conducted among children aged 9 to 10 years [39]. In a recent study, WHtR was reported to be the best predictor of adolescents' BP regardless of age and sex compared to BMI, WC and ABSI [45]. In the study by Tee et al. [45] conducted among adolescents aged 12 to 16 years, WHtR reportedly had good sensitivity and specificity (>70%) in predicting BP. Besides that, we also found that age was negatively associated with SBP and DBP. In contrast, Sreeramareddy et al. [39] reported that age was positively associated with DBP. This might be due to the strong positive associations that were found between obesity indicators (BMI, WC, WHtR) and hypertension risk, which conceal the age-related effect towards hypertension risk.

Duncan et al. [5] reported that ABSI was a more sensitive method in predicting blood pressure in adolescents. ABSI is based on BMI and WC, which takes into account the deposit of fat in the abdominal region. Thus, individuals with higher accumulation of visceral fat, rather than peripheral fat tissue, have a higher risk of developing metabolic syndrome [11]. However, our study did not find any associations of ABSI with SBP and DBP. Therefore, the predictive power of ABSI might have been confounded by other variables. The lack of data on physical activity level and metabolic profile of the participants adds as limitations that may confound the present findings.

Notably, this study did not find any correlation between birth weight and the risk of hypertension. Similarly, a couple of previous studies of children between the ages of nine to 13 years old also did not find any associations between birth weight and BP [46,47]. Compensation of poor growth, resulting in weight gain, later in life, as a consequence of LBW in early life, is a plausible explanation for elevated BP among adults born with LBW. There is also evidence that children's weight gain after birth influences BP more than low birth weight per se [48]. Furthermore, the low incidence of LBW (12.6%) cases in our sample could also be inadequately powered to demonstrate the association with blood pressure. This study emphasizes that the relationship between birth weight and BP is complex and may vary depending on the effects of gestational age and growth [49]. Therefore, further research is essential to identify the mechanism linking LBW to hypertension and other metabolic health sequelae.

Studies on the relationship between anthropometric indices with BP in Malaysian adolescents are still limited. Therefore, our current findings are crucial in shaping future studies and interventions relevant to hypertension issues within similar populations of this study. Although the cross-sectional design of the present study does not allow establishing a cause-effect relationship between anthropometric indices and high BP in adolescents, our current findings assessed multiple anthropometric indices in predicting the incidence of elevated BP among Malay adolescents. Moreover, since Rampal et al. [50] determined that in Malaysia, the highest prevalence of obesity was among individuals of Malay ethnicity, this underlines the importance of our findings among Malay adolescents. Many other risk factors for elevated BP can be investigated in future studies, including genetic inheritance, premature birth, secondhand smoke, lower socioeconomic status, poor diet, reduced activity, sleep deprivation, and increased stress that contribute to hormonal and metabolic alterations, as well as the development of obesity and hypertension during adolescence.

6. Conclusion

The present study found a prevalence of hypertension and prehypertension at 4.7% and 3.9%, respectively, among Malay adolescents in Kuala Lumpur. Although this prevalence is not particularly high, it raises concern as the study also confirms a positive relationship between obesity and BP. Additionally, adolescents with higher BMI, WC and WHtR have higher odds of developing hypertension. These findings strongly emphasize the importance of primary prevention of hypertension in adolescents, especially among those with high BMI. As high prevalence of overweight (12.6%) and obesity (18.9%) was reported in this study, strategizing a more comprehensive healthcare system, including early detection, counselling and skill building is rather important. With the aim of improving the country's public health system, focusing on reducing mortality from hypertensive-related comorbidities will avoid overburdening the healthcare system, in terms of human resources, financial system and other economic resources. Besides that, investing in digital health intervention is urgently needed in Malaysia, as regular monitoring on chronic diseases can reduce the development of comorbidity sequalae risk in later life. Integrating the digital technology-based tools in the healthcare therapeutic system can encourage behavior or lifestyle changes among patients by offering personalized feedback and routine monitoring their health conditions.

Funding

This project is supported by a grant from the International Atomic Energy Agency (IAEA) Coordinated Research Project (Project Code: E4.30.24; UKM Project Code: NN-101-2010).

Availability of data and materials

The data used to support the findings of this study are available from the corresponding author upon request.

Ethics approval and consent to participate

This study procedures involving human subjects/patients were approved by the Research Ethics Committee of Universiti Kebangsaan Malaysia (UKM 1.5.3.5/222/NN-084-2011). Written informed consent was obtained from the parents or guardians for all adolescents.

Patient consent for publication

Not applicable.

Informed consent

Written informed consent from the parents or guardians and verbal assent from participants were obtained prior to data collection.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Acknowledgements

We thank the Ministry of Education Malaysia and the Department of Education in the Federal Territory of Kuala Lumpur for permission to conduct the study. The authors appreciate the support and cooperation of all the participants, parents, teachers, school administrative staffs and the data collection team throughout this study.

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